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Dimensions of Mechanical Fibres in *Paulownia elongata* S. Y. Hu Wood from Different Habitats

Dimenzije libriformskih vlakanaca *Paulownia elongata* S. Y. Hu s različitih staništa

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ABSTRACT • *Paulownia elongata S. Y. Hu, has exceptionally fast growth in juvenile stage (more than 3 m in the second year). Due to its characteristic of easy generative and vegetative propagation (tissue culture) and renewal, it currently presents the most suitable plant for biomass production in our region, with short rotation time. Poplar clones provide raw material for paper and pulp industry at the moment, and this industry is the biggest softwood consumer in Serbia. Anatomical properties of wood mechanical fibres in Paulownia elongata S. Y. Hu juvenile wood have not been researched in Serbia, since this species has been recently introduced from China (1993). The aim of this paper is to explore the impact of habitats (soil) and fertilisation on wood fibre dimensions in juvenile wood of Paulownia elongata S. Y. Hu. Samples for research of wood fibres originate from experimental plantations of Paulownia elongata S. Y. Hu, 2 years of age, from two different sites: Obrenovac-Veliko polje and Ub-Pambukovica. Based on research of wood anatomy, it has been concluded that there are significant statistical differences in wood fibre dimensions in Paulownia elongata S. Y. Hu from different habitats. Research of wood fibre dimensions in Paulownia elongata S. Y. Hu juvenile wood from two different sites contributes to determine its use for the pulp industry, which supports cultivation of this fast growing species (Table 3, 4 i 5).*

Key words: *wood fibre, Paulownia elongata S.Y.Hu, soil, wood anatomy*

SAŽETAK • *Paulownia elongata S. Y. Hu svojim svojstvom iznimno brzog rasta u juvenilnoj fazi razvoja, kao i mogućnostima jednostavnoga generativnoga i vegetativnog razmnožavanja (kultura tkiva) i obnove nasada trenutačno je najprikladnija vrsta s kratkom ophodnjom za proizvodnju biomase u našoj regiji. U ovom su trenutku klonovi topola sirovina za industriju celuloze i papira, koja je najveći potrošač mekih listača. Anatomska svojstava libriformskih vlakanaca Paulownia elongata S. Y. Hu u juvenilnoj fazi razvoja još nisu istražena u Srbiji jer je Paulownia elongata S. Y. Hu uvezena iz Kine u Srbiju tek 1993. godine. Cilj ovog rada bio je istražiti utjecaj staništa (tla) i utjecaj gnojidbe na dimenzije libriformskih vlakanaca Paulownia elongata S. Y. Hu u juvenilnoj fazi razvoja. Uzorci za istraživanje dimenzija libriformskih vlakanaca podrijetlom su iz pokusnih nasada Paulownia elongata S. Y. Hu starih dvije godine s dva različita mjesta: Obrenovac - Veliko Polje i Ub - Pambukovica. Na*

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temelju rezultata istraživanja anatomske strukture zaključeno je da postoje statistički značajne razlike u dimenzijama libriformskih vlakanaca u Paulownia elongata S. Y. Hu. s različitih staništa te da je stanište imalo utjecaja na te različitosti (tabl. 3., 4. i 5.). Istraživanja dimenzija drvenih vlakana juvenilnog drva Paulownia elongata S. Y. s dva različita staništa pridonijela su potvrdi njezine uporabe za industriju celuloze, što podržava uzgoj te brzorastuće vrste.

Ključne riječi: *libriformska vlakanca, Paulownia elongata S. Y. Hu, tlo, anatomija drva*

1 INTRODUCTION
1. UVOD

Paulownia elongata S. Y. Hu is characterised by its excessively fast growth in the juvenile phase (vertical growth is up to 4 m during the second year and within the same period the growth in diameter is about 5 - 7 cm), as well as by its easy generative and vegetative propagation (tissue culture) and plantation renewal (Šoškić *et al.*, 2003). *Paulownia elongata* characteristics show that the species is recommended for biomass production. (Vilotić *et al*., 2011).

There are many factors, such as soil and climate, that affect the anatomical properties of wood (Zhang, 1992; Vilotić and Knežević, 1994; Vilotić, 2000; Hacke and Sperry, 2001). Esteban *et al*. (2010) and Vilotić and Knežević (1994) state that ecological environmental circumstances have affected significantly not only the properties of the tree, but also the dimensions of its conductive cells. Venugopal and Liangkuwang (2007) state that there is an obvious correlation between climatic parameters, activities of vascular cambium and xylem formation. Research has shown that the physical and chemical characteristics of soil have a great influence on macroscopic characteristics, microscopic structure, density, and physical, mechanical and technological properties of wood (Vilotić, 1992; Vilotić *et al*., 2005; Šoškić *et al*., 2003).

Paulownia elongata S. Y. Hu was introduced from China to Serbia in 1993. Anatomical characteristics of its wood fibres in juvenile wood have not been researched so far. The goal of this paper was to examine: a) the influence of habitat (soil) on juvenile wood fibre dimensions in *Paulownia elongata* S. Y. Hu; and b) the influence of fertilisation on juvenile wood fibre dimensions of *Paulownia elongata* in different habitats.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

Samples used for research of the influence of habitat and feeding on the dimensions of wood fibres were taken from experimental 2-year-old plantations of Paulownia elongata S. Y. Hu, at two different sites: Obrenovac-Veliko polje and Ub-Pambukovica.

2.1 Climate
2.1. Klima

Obrenovac is located almost in the middle of a northern, moderate continental strip, with the climate milder than the typical Pannonian continental one. The climate in Pambukovica is a moderately continental one, with certain distinctive characteristics. The basic climate factors for the areas of Obrenovac and Pambukovica are given as the average monthly temperatures (Figure 1) and the average monthly precipitations (Figure 2), for the period from 1948 to 2012. The climate data for Obrenovac and Pambukovica areas were taken from the monitoring stations in Belgrade and Valjevo, respectively. Both monitoring stations are supervised by the Republic Hydrometeorological Service of Serbia.

Figures 1 and 2 show similar climate for the areas of Obrenovac and Pambukovica, in terms of the average monthly temperatures and the average monthly precipitations. The annual distribution of precipitations is very favourable for the agricultural production (the precipitation increases throughout the whole spring) (Pavlović *et al*., 2011).

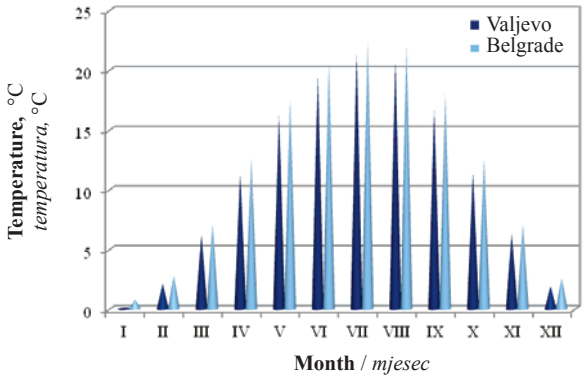

Figure 1 Average monthly temperatures (°C) measured at the monitoring stations in Valjevo and Belgrade
Slika 1. Srednje mjesečne vrijednosti temperature (°C) za postaje Valjevo i Beograd

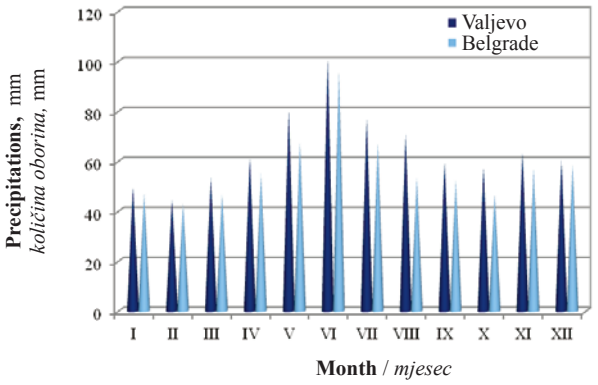

Figure 2 Average monthly precipitations (mm) measured at the monitoring stations in Valjevo and Belgrade
Slika 2. Srednje mjesečne vrijednosti oborina (mm) za postaje Valjevo i Beograd

Table 1 Basic characteristics of soils in Obrenovac and Pambukovica areas
Tablica 1. Osnovna svojstva tla s područja Obrenovca i Pambukovice

Site *Mjesto*	**Soil texture** Tekstura tla	**Hydraulic permeability** *Propusnost tla za vodu*	**Aeration** *Kapacitet tla za zrak*	**pH value in H_2O** *pH u H_2O*	**Total humus content** *Sadržaj humusa*
Obrenovac	clay / *glina*	poor / *slaba*	poor / *slab*	5.7	low / *nizak*
Pambukovica	clay / *glina*	poor / *slaba*	poor / *slab*	5.0	low / *nizak*

2.2 Soil
2.2. Tlo

Table 1 shows physical and chemical soil characteristics in Obrenovac and Pambukovica. The low level of humus content in soils suggests that the total nitrogen content is also low. In addition, the lack of the organic substances and phosphorous is also notable, although potassium is present in satisfactory amounts.

2.3 Treatments
2.3. Tretmani

In order to improve the nutritive values of these soils, the organic fertilizer was used at both sites. Three sample groups were taken from each site. Two sample groups (from each site) were treated with the combination of fertor (chicken fertilizer) and polimer (the quantities of the components are given in Table 2). In addition, the sand and the Sunoko calcification agent were used at the Pambukovica site. The sand was added to improve the physical properties of the soil, while the Sunoko calcification agent was added to decrease the soil acidity. The effects of the treatments on both sites were evaluated in regard to the control sample group (from each site), which has not been treated.

Fertor is an organic fertiliser, composed of 100 % of chicken fertiliser, improved by other organic substances of plant origin, increasing and enhancing the fertiliser nutritive value. In addition to main elements (N, P, K, Ca and Mg), it also contains microelements (Fe, Mn, B, Zn, Cu). Part of the macro and micro elements is easily accessible and readily available for the plant, while the remainder is gradually released (Web Source 1).

Sunoko calcification agent is an inorganic improving agent for the soil, suitable for all plant culture as a fertiliser and agent for the enhancement of soil properties. It is recommended for all types of soil, whose pH value is lower than 5.5, as is the case with Pambukovica soil. With a content of minimum 70 % of $CaCO_3$ and $MgCO_3$, but also P, K, Fe, as well as Mn, Zn, Cu, Co and pH value of 8.22, it improves the structure and pH value of acidic soils, and returns microelements into the soil, thus improving soil fertility (Web Source 2).

2.4 Sampling and preparation of samples
2.4. Uzorkovanje i priprema uzoraka

The samples were taken from root collars, as rolls 1 cm thick. These were chopped into match-size pieces and macerated in order to obtain individual cells of wood tissue suitable for measuring mechanical fibre dimensions.

Wood tissue maceration of *Paulownia elongata* samples was carried out using Franklin's reagent (Franklin, 1945), a mixture of 30 % of hydrogen peroxide and glacial acetic acid in the ratio 1:1.

2.5 Measuring wood fibre dimensions
2.5. Mjerenje dimenzija drvnih vlakanaca

Measurement of length and width of mechanical fibres of *Paulownia elongata* was carried out at the Institute for Forestry in Belgrade, using an optical microscope, augmenting the sample magnified 40 times, using the "Image Tool" programme.

The mean fibre length and the mean fibre width were obtained from 30 measurements (30 fibres) on each of the three samples that made one sample group. The results were statistically analyzed by the single factor ANOVA test.

Table 2 Coding of samples and applied treatments
Tablica 2. Prikaz označivanja uzoraka i primijenjenih tretmana

Site *Mjesto*	**Sample group** *Oznaka grupe uzorka*	**Sample age (year)** *Starost uzoraka (godina)*	**Number of samples** *Broj uzoraka*	**Treatment** *Tretman*	
Obrenovac	OB.1	2	3		25 g polimer 250 g fertora
	OB.2	2	3		25 g polimer 125 g fertor
	OB.3 (Control)	2	3	/	
Pambukovica	P.1	2	3	1250 g sand 1 kg Sunoko calcification agent	25 g polimer 250 g fertor
	P.2	2	3		25 g polimer 125 g fertor
	P.3 (Control)	2	3	/	

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

Wood fibres are the mechanical elements present in the *Paulownia elongata* tree. These are prosenchima elements, very sharp at the ends.

Statistical analysis of measured lengths and widths of mechanical fibre samples from juvenile sprouts enabled an overview of the influences of feeding and habitat on the dimensions of *Paulownia elongata* wood fibre. By the analysis of measured values within each of the sampling groups, minimum and maximum measured and mean values were obtained for lengths and widths of fibres. From the mass of 90 measurements per sample, minimum and maximum values were selected for each group. Mean values for fibre lengths and widths were obtained as arithmetic mean values of those measured in each sampling group. This procedure was applied to all sampling groups and both habitats.

Minimum, maximum and mean values, as well as standard deviations of fibre length in *Paulownia elongata* control and treated samples taken from these two habitats are shown in Table 3. The results of the multiple range tests for both fibre length and fibre width of the *Paulownia elongata* are given in Table 4.

3.1 Influence of habitats on the length of wood fibre
3.1. Utjecaj staništa na duljinu drvnih vlakanaca

The influence of habitat on the dimensions of wood fibres can be seen through the comparison of values of fibre length of *Paulownia elongata* control samples (those without fertilising) and the researched habitats.

Tables 3 and 4 show significant statistical differences in the fibre length of the control samples (OB.3 and P.3) from these two sites. Fibre length of samples of *Paulownia elongata* cultivated in Obrenovac have a mean value of 0.459 mm, while the mean value of samples of the same age taken from the site of Pambukovica is 0.371 mm.

In addition, it is interesting to compare maximum measured lengths of fibres from these two sites. It can be seen that the maximum measured fibre length of 1.25 mm recorded for a plant cultivated in Obrenovac is twice as long as the maximum measured fibre length of 0.57 mm measured in a plant cultivated in Pambukovica.

This discrepancy in mean and maximum values of fibre length in control samples from these sites indicates that the habitats and their properties greatly influenced the fibre length.

Research conducted by Popović and Radošević (2011) showed that mean mass and mean numerical length of fibres measured on a 12-year old *Paulownia elongata* cultivated in an experimental plantation in Bela Crkva, ranged between 0.985 and 1.022 mm, while values measured on *Paulownia fortunei* (the same age, from the same location) in terms of mass and numerical length of fibres were somewhat smaller and ranged between 0.783 and 0.818 mm (Popović and Radošević, 2008). Similar values for *Paulownia elongata* fibre length of 0.96-1.19 mm were stated by Cheng (1983). Having in mind that the 2-year old *Paulownia elongata* (Table 3), cultivated in the Republic of Serbia, has the average fibre length in the range between 0.371 and 0.459 mm, it could be assumed that

Table 3 Fibre length values for *Paulownia elongata* for different treatments
Tablica 3. Vrijednosti duljina vlakanaca *Paulownia elongata* za različite tretmane

Site / *Mjesto*	**Obrenovac (OB)**				**Pambukovica (P)**			
Sample group *Oznaka grupe uzoraka*	**min** mm	**max** mm	**Mean value** *Srednja vrijednost* mm	**Standard deviation** *Standardna devijacija*	**min** mm	**max** mm	**Mean value** *Srednja vrijednost* mm	**Standard deviation** *Standardna devijacija*
OB.3/P.3 (Control)	0.15	1.25	0.459	0.1700	0.21	0.57	0.371	0.0850
OB.1/P.1	0.21	0.64	0.441	0.0976	0.22	0.77	0.457	0.1002
OB.2/P.2	0.21	0.70	0.409	0.0973	0.22	1.29	0.478	0.1529

Table 4 Statistical analysis of results obtained by measuring fibre length and fibre width (ANOVA)
Tablica 4. Rezultati statističke analize rezultata mjerenja duljine i širine vlakanaca (ANOVA)

Pairs of sample groups *Parovi grupa uzoraka*	**Fibre length** *Duljina vlakanaca*			**Fibre width** Širina vlakanaca		
	F	F crit	*P*-value	F	F crit	*P*-value
OB.3 - P.3	19.14094	3.894232	*2.06E-05	4.537981	3.894232	*0.034524
OB.1 - OB.2	0.889036	3.894838	0.347031	2.460193	3.894838	0.118561
OB.1 - OB.3	3.193978	3.894232	0.075612	0.792211	3.894232	0.374634
OB.2 - OB.3	5.473616	3.894838	*0.020428	6.152337	3.894838	*0.014064
P.1 - P.2	3.334355	3.894232	0.069523	20.219635	3.894232	*1.24E-05
P.1 - P.3	39.496385	3.89364	*2.41E-09	17.711687	3.894232	*4.07E-05
P.2 - P.3	11.522480	3.89364	*0.000846	6.05E-13	3.894232	0.999999

* denotes a statistically significant difference / *označava statistički značajnu razliku*

Table 5 Fibre width values for *Paulownia elongata* for different treatments
Tablica 5. Vrijednosti širine vlakanaca *Paulownia elongata* pri različitim tretmanima

Site *Mjesto*	**Obrenovac (OB)**				**Pambukovica (P)**			
Sample group *Oznaka grupe uzoraka*	**min** µm	**max** µm	**Mean value** *Srednja vrijednost* µm	**Standard deviation** *Standardna devijacija*	**min** µm	**max** µm	**Mean value** *Srednja vrijednost* µm	**Standard deviation** *Standardna devijacija*
OB.3/P.3 (Control)	10	50	21	7.3	10	30	23	7.9
OB.1/P.1	10	40	22	6.7	10	40	27	5.2
OB.2 / P.2	10	40	23	6.2	10	40	24	6.5

there is an increasing trend in fibre length with the increasing age, for this wood species.

3.2 Influence of fertilising on the length of wood fibres
3.2. Utjecaj gnojidbe na duljinu drvnih vlakanaca

Statistical analysis of the length and width of the mechanical fibres of *Paulownia elongata* samples provide the possibility to determine the influence of various treatments on the fibre dimensions. For that purpose, the results of the treated samples were compared with the results obtained from the control sample group at the related site (Table 4).

Based on the analysis of fibre length mean values for the Obrenovac site, presented in Table 3, it can be concluded that the fibre length mean value of 0.459 mm in the control sample is higher than the fibre length of samples treated by fertiliser (0.441 and 0.409 mm), which indicates that fertilising did not positively affect the length of wood fibres in this habitat.

Table 3 also shows mean values for *Paulownia elongata* fibre lengths from the Pambukovica site. In addition, it can be noticed that fibre length mean value of 0.371 mm in a control sample (P.3 sample) has the lowest value, while mean values of fibres taken from fertilised samples (P.1 and P.2) of 0.457 mm and 0.478 mm, respectively, are significantly higher (Table 4). Based on that, it can be concluded that fertilising had a positive influence on fibre length in the Pambukovica site.

Table 5 shows mean values and standard deviation, as well as maximum and minimum values measured for fibre width in control and fertilised samples of *Paulownia elongata* from these two habitats.

3.3 Influence of habitat on width of wood fibres
3.3. Utjecaj staništa na širinu drvnih vlakanaca

It can be observed that mean values of fibre width measured in control samples of *Paulownia elongata* cultivated in Obrenovac and Pambukovica, shown in Table 5, do not show statistically significant differences (Table 4). The maximum measured value of fibre width in control samples cultivated in Obrenovac of 50 µm is somewhat higher than fibre width in control samples cultivated in Pambukovica of 30 µm, while the minimum measured values of fibre width in control samples cultivated in these two habitats are identical. These results suggest that the site itself had no influence on the fibre width.

3.4 Influence of fertilising on width of wood fibres
3.4. Utjecaj gnojidbe na širinu drvnih vlakanaca

Treated sample group OB.1 (Obrenovac site) showed 1 µm higher values of mean fibre width in comparison to non-treated samples (OB.3), which is not a statistically significant difference. Mean fibre with of the treated sample group OB.2 was significantly higher in regard to the control samples (Table 5 and Table 4).

The differences of the mean fibre values between the treated and the control samples are higher at the Pambukovica site (in regard to Obrenovac site), and they are statistically significant when comparing the P.1 sample group with the other two.

Minimum values of fibre width measured in fertilised and untreated samples taken from both habitats are the same. As for maximum values of measured fibre width, control samples taken from the Obrenovac site are a little bit higher than fertilised ones, while maximum measured values of fibre width in control samples taken from the Pambukovica site are a little bit lower than in fertilised samples. However, the statistical analysis of the results does not provide the confirmation that the observed differences occurred as the consequence of the treatments.

4 CONCLUSIONS
4. ZAKLJUČAK

Based on the conducted research, it can be concluded that there are differences in fibre lengths measured in control samples of *Paulownia elongata* from different habitats, indicating that habitat with its properties (climate, soils, and so on) affects the fibre length.

Taking into account that fibre length measured in control samples from Pambukovica shows significantly lower values compared to the ones from Obrenovac, it can be concluded that habitat in Pambukovica is not suitable for this plant species.

Differences in fibre width measured in control samples of *Paulownia elongata* from different habitats are not significant, which leads to the conclusion that habitat did not affect the fibre width.

The treatments performed at the Obrenovac site did not have a positive influence on the fibre length, according to the statistical analysis of the fibre length values for the control and the treated samples.

Significant difference in the fibre length was found between both treated sample groups in regard to the control group from the Pambukovica site. The lowest mean value of fibre length of 0.371 mm was recorded with the control sample group (P.3), while sample groups of P.1 and P.2 which were treated, had higher mean values of fibre length of 0.457 and 0.478 mm, respectively, indicating that fertilising influenced the fibre length of *Paulownia elongata* at the Pambukovica site.

Significant differences in fibre width on both sites were only recorded between the treated and the relative control sample group (OB.2 – OB.3 i P.1 – P.3). Therefore, it cannot be confirmed that there was a significant influence of the fertilizing treatments on the fibre width of *Paulownia elongata*.

Tests conducted in relation to the juvenile wood fibre length of *Paulownia elongata* S. Y. Hu from two different sites confirmed that its very young wood could be used as raw material for pulp production, and that cultivation of this plant species was possible in our country.

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